

Pulse Power Systems and Diagnostics for the Fixed Hybrid Armature Railgun



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Plasma physics within the confines of railgun science is not well understood. Since plasma *re-strike* is primarily responsible for limiting ultra-high velocities (UHV) and equation of state (EOS) studies, there is a great need to predict and control this behavior.

For this purpose, we have rebuilt and explored a Fixed Hybrid Armature (FHA) railgun. In these experiments, plasma brushes are formed from exploding aluminum foils, which then provide a current path through the armature. Since the armature is fixed in place, a pseudo-steady-state is achieved and diagnostic investigation of the plasma is confined to a small region (Fig. 1).

We have implemented a suite of diagnostics, including two arrays of Bdots (B-field sensors) used to measure the magnetic fields produced by the plasma

currents as a function of position (Fig 2). Plasma position is also measured by the use of a fiber optic photo emission array. Total current is measured by a single Faraday rotation diagnostic and Rogowski coils positioned on the upper rail of the FHA railgun and on each module of the capacitor bank. Plasma pressure is obtained by both a piezoelectric quartz sensor and a fiber optic Bragg grating sensor. Voltage measurements are performed across the plasma brushes, from rail to rail, and also on the modules of the capacitor bank.

Eleven experiments over a range of total currents from 164 kA to 475 kA have been performed. Experimental data has been provided to the UHV railgun project and applied to the validation of a new plasma model in ALE3D, a multiphysics computational platform.

Project Goals

The primary goal of this project was to provide diagnostic data with sufficient

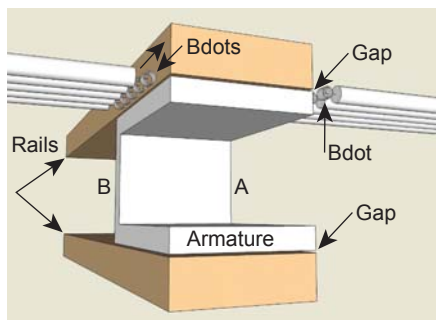


Figure 1. Depiction of the Fixed Hybrid Armature railgun. The armature is floating, thus a small gap (~1 mm) exists between it and the rails. This gap contains conducting plasma that changes parameters such as location, density, and temperature over the length of the experiment. Two arrays of five Bdots are installed on each side of the top of the armature and are oriented to be sensitive to the magnetic field of the current through the plasma.

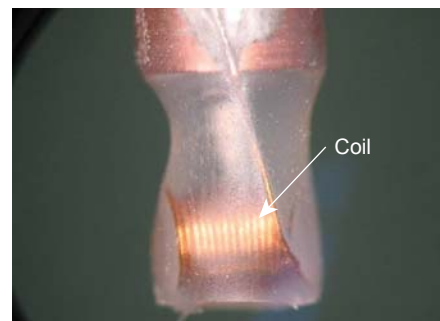


Figure 2. The Bdot sensors are heat-shrink encapsulated 15-turn loop antennas with 0.077-in.-diameter turns of 0.006-in.-thick wire. The loops are wrapped around a mandrel and soldered to semi-rigid coaxial cable, then imbedded in the insulating walls of the FHA railgun.

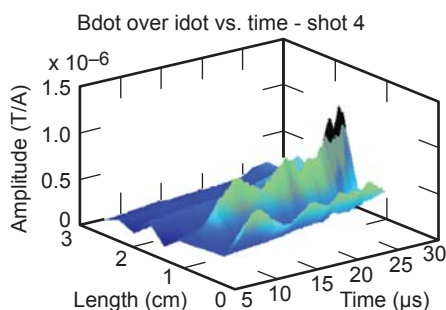


Figure 3. Bdot sensor data divided by total current gradient (idot) as measured by the Rogowski diagnostic positioned on the rail. Plasma generated magnetic field distribution varies in strength and position over time.

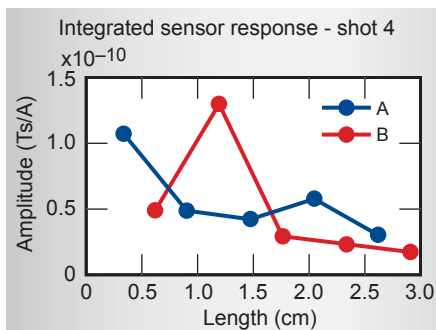


Figure 4. The integral of Bdot over idot response with respect to time, generates a total magnetic field contribution within the time window of interest. Clearly, side B of the FHA railgun received a larger contribution of signal than side A.

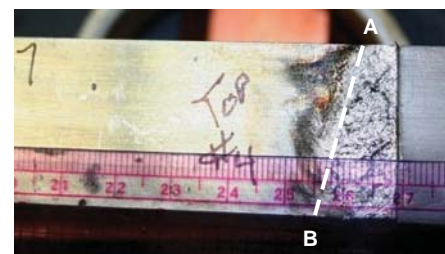


Figure 5. A post-mortem photograph of the armature reveals a skewing in the ablation of the aluminum armature. This skewing is predicted by the integrated response of the Bdot data shown in Figure 4.

resolution and relevance to validate a plasma model in ALE3D that is applicable in the railgun regime. To achieve this, we assembled the FHA railgun and configured a test bed for the application of high-energy pulsed power and sensitive diagnostics.

Relevance to LLNL Mission

This project directly addresses immediate needs in the LLNL's Engineering Energy Manipulation Focus Area Roadmap. These include the creation of a railgun test bed and high-energy diagnostic systems. Also addressed is the investigation of the feasibility of UHV railguns. These goals directly impact many pulsed power programs at LLNL and support the commitment to UHV and EOS research and shock physics.

ALE3D is a 3-D multiphysics computational platform. With the addition of a plasma model, this code has a wide range of application, including the understanding of high-energy pulsed-compression generators.

FY2008 Accomplishments and Results

By leveraging legacy hardware from the early 1990s, we assembled the FHA railgun test facility. The first experimental shot was performed in FY2007, successfully delivering 290 kA to the

FHA railgun. In FY2008, we continued these experiments for a total of eleven shots over a range of total currents from 164 kA to 475 kA.

Diagnostic fidelity improved in FY2008 by fine tuning of the recording parameters for the Bdot array and Rogowski coils. Work on the fiber optic emission array and pressure sensor diagnostic continued and we achieved successful recordings over a few of the experiments. We also added voltage measurements to the breach end of the FHA railgun, as well as to the top and bottom plasma brushes.

A vast amount of measurement data has been generated, processed, and analyzed. A typical example of the Bdot time history data is given in Fig. 3, which shows how the plasma-generated magnetic field varies over time and space. The total contribution of this field over time is shown in Fig. 4. Here, the data suggests a distinct imbalance is

between each side of the armature. This imbalance is confirmed in post-mortem photographs of the armature shown in Fig. 5.

The raw and processed data from all of the diagnostics are currently being applied to the validation of a new plasma model in ALE3D.

Related References

1. Drobyshevski, E. M., *et al.*, "Physics of Solid Armature Launch Transition into Arc Mode," *IEEE Transactions on Magnetics*, **37**, 1, pp. 62–66, 2001.
2. Hawke, R. S., *et al.*, "Summary of EM Launcher Experiments Performed at LLNL," *IEEE Transactions on Magnetics*, **22**, 6, pp. 1510–1515, 1986.
3. Hawke, R. S., *et al.*, "Plasma Armature Formation in High Pressure, High-Velocity Hydrogen, Starfire: Hypervelocity Rail Gun Development of High Pressure Research," *IEEE Transactions on Magnetics*, **25**, 1, p. 219, 1989.

FY2009 Proposed Work

The FHA railgun and capacitor bank provide a test bed for the continuation of experimental investigations concerning railgun plasmas. Additional experiments are planned for the testing of advanced non-ablating materials and for continued work on fiber optic sensors.